

**Developing Nationally Competitive NASA Research Capability
in West Virginia**

Final Report

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Submitted by

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I. Introduction

In May, 1995 West Virginia EPSCoR was awarded \$150,000 to support activities to develop research capabilities in West Virginia in support of the National Aeronautics and Space Administration (NASA). These funds were used to support three projects: 1) Information Processing and the Earth Observing System, directed by Dr. Stuart Tewksbury of West Virginia University; 2) Development of Optical Materials for Atmospheric Sensing Experiments, directed by Dr. Nancy Giles of West Virginia University; and 3) Development of Doppler Global Velocimeter (DGV) for Aeronautical and Combustion Studies, directed by Dr. John Kuhlman of West Virginia University. The funding provides the means to develop capability in each of these areas. This report summarizes the technical accomplishments in each project supported under this award.

II. Development of Optical Materials for Atmospheric Sensing Experiments

Nancy C. Giles, Associate Professor of Physics, West Virginia University
Thomas H. Myers, Associate Professor of Physics, West Virginia University
Thomasina Redd, Professor, Alderson Broaddus College

The goal of this project was to initiate experimental materials research in the Department of Physics at West Virginia University in areas that would directly support activities of interest to NASA. Two areas in materials research were chosen for our initial focus: (1) infrared nonlinear optical materials such as silver gallium diselenide (AgGaSe₂) and zinc germanium diphosphide (ZnGeP₂) for use in high-power tunable mid-infrared lasers; and (2) thin films of gallium nitride (GaN) grown by molecular beam epitaxy for ultraviolet sensors and light emitters. A subcontract to Alderson Broaddus College was included as an initiative to provide students at an undergraduate institution opportunities in research. The funds received in this start-up effort were distributed as follows:

(1) Start-up effort in infrared nonlinear laser materials	\$21,604
(2) Start-up effort in MBE growth of GaN	\$21,000
Subcontract to T. Redd, Alderson Broaddus	\$ 7,396

TOTAL	\$50,000

The first research focus area, which was on nonlinear optical materials, was directed by Dr. Nancy Giles. Of the allocated amount, \$20,000 was used to complete the purchase of a high-power, pulsed Nd:YAG laser system (Continuum Powerlite 9000) with a tunable KTP optical parametric oscillator. The remaining funds used to purchase the Nd:YAG laser were obtained from a NASA-sponsored project (the NASA/WV Unmanned Aerial Vehicle program), and the National Research Center for Coal and Energy (located on the campus of WVU). Crystals of the nonlinear optical materials AgGaSe₂ and ZnGeP₂ were obtained from an industry partner (Sanders, Nashua, NH), and the high-power laser system was used in transient absorption studies. The acquisition of the laser/OPO system also provided a test-bed for development of the mid-infrared OPO materials. The remaining \$1,604 allocated to this part of the NASA EPSCoR

project was used to purchase small optical components to be used with the laser system.

The NASA EPSCoR funds used to support the nonlinear optical materials have continued to pay off in developing further ties to NASA research programs. The Nd:YAG laser system was used during the past year to complete project tasks associated with a NASA-sponsored SBIR Phase I program with Cleveland Crystals (Cleveland, OH). This SBIR project involved the characterization of point defects limiting device performance in beta-barium borate (BBO) nonlinear optical crystals. The BBO crystals are used in high-power pulsed lasers for atmospheric science applications that NASA is interested in. The NASA project monitor on this SBIR is Dr. Norman Barnes (NASA Langley, Hampton, VA). The Phase I component was completed this fall, and a Phase II proposal is presently pending.

The second research focus area on GaN thin films was directed by Dr. Thomas Myers. The NASA EPSCoR funding initiated the gallium nitride (GaN) molecular beam epitaxy growth and characterization effort presently ongoing in the Department of Physics. The funds allocated for this part of the overall project allowed materials and supplies to be purchased so that a few initial GaN growths could be performed in the molecular beam epitaxy lab at WVU. This initial work was presented in a talk given at the Jet Propulsion Laboratory (Pasadena, CA) in 1996.

"Energy Assisted Molecular Beam Epitaxy of Gallium Nitride", T. H. Myers, N. C. Giles and C. E. Stinespring, Selected Energy Epitaxy Workshop, Jet Propulsion Laboratory, Pasadena, CA (January, 1996).

The NASA EPSCoR monies directly supported a research tie to one of the NASA laboratories. During the start-up period supported by the EPSCoR funds, five GaN samples grown by molecular beam epitaxy were provided to the Jet Propulsion Laboratory group directed by Dr. Paula J. Grunthaner (Tel (818) 354-0360) for device characterization. Dr. Grunthaner's interests are in GaN materials development and high power microwave devices. She is Supervisor of the Semiconductor Sensor Technology Group at the Jet Propulsion Laboratory, and the initial EPSCoR funds established a direct tie between Dr. Myers' program and a NASA lab.

The NASA EPSCoR funds to support the GaN research, along with a small grant from the NASA/WV Space Grant Consortium, have led now to a successful funded research program at WVU. More recent funding for GaN work has been obtained by Dr. Myers and includes:

"An Investigation of the Effects of Hydrogen on the Growth Kinetics and Defect Formation in Group III-Nitride Semiconductors", T. Myers, Office of Naval Research, Award Amount \$316,897, Duration 9/1/96 to 8/31/99.

"Energy Assisted Molecular Beam Epitaxy of Gallium Nitride Using a Low-Ion-Flux Nitrogen Atom Source", T. Myers, with N. C. Giles and C. D. Stinespring, Office of Naval Research, Award Amount \$322,813, Duration 8/15/95 to 8/14/97.

III. Heterogeneous, Parallel Computation Environments

S. Tewksbury, Professor of Electrical and Computer Engineering,
Department of Computer Science and Electrical Engineering,
West Virginia University

The project involved four investigators, with general research activities as follows: 1) DSP array accelerators and their software development environment, led by Dr. Stuart K. Tewksbury of the Department of Electrical and Computer Engineering, West Virginia University; 2) Techniques and tools for IV&V, led by Dr. Hany Ammar of the Department of Electrical and Computer Engineering, West Virginia University; 3) Numerical computation algorithms and their execution on a parallel computing system, led by Dr. Herb Tesser of the Department of Computer Science, Marshall University; and 4) Dataset communications between a central computer and remote workstation sites, led by Dr. Trevor Harris of the Department of Geology and Geography, West Virginia University.

The NASA/EPSCoR program, summarized below, was established for the purpose of developing a larger NASA/EPSCoR research program, but since the proposal for that larger program was not awarded, the results of the research program described here are largely related to tasks clarifying various topics which would have been expanded as more substantial research projects in the follow-on program which was not awarded.

The work on DSP array accelerators reviewed opportunities in the hardware architectures of parallel computational accelerators using high performance digital signal processors. Information on the approaches of several parallel computer and parallel DSP system manufacturers was acquired, with the decision to base the studies on arrays of smaller clusters implementing limited complexity parallel DSP computing "cells". The Analog Devices SHARC DSP was selected as the most appropriate vehicle for studies, based on its parallel I/O capabilities and similarity to the Transputer (Inmos, Ltd) architecture. Basic "signal flow" graph models were exploited to develop a "computational" architecture for data movement among the memory storage locations and the computational engines. The image processing applications generally allow a file to be copied to a local computing site, used to generate a new file, and to be simply discarded (the local copy) when no longer needed. An evaluation of a wide range of technologies and techniques for very high speed interconnection of several computing elements with each other and with distributed memory elements was completed. Basic ring architectures (e.g., Scalable Coherent Interface and similar approaches) were determined to be the most flexible architectures, though limited by the ability to provide low latency, direct data flow between a particular memory component and a particular computation component. During the period of the NASA program, the PI was exploring similar topics within a consulting position with a corporation and a government research funding organization (with restrictions that neither the corporation or the government organization can be identified). The basic concepts developed were incorporated within a proposal for an NSF/EPSCoR research cluster proposal ("Medical Imaging and Image Processing") which received initial funding. A graduate student (Jennifer

Rourke - female, US citizen) was funded by this NASA program.

Peer-reviewed journal publications fully or partially based on the NASA/EPSCoR research are as follows.

1. S.K. Tewksbury and L.A. Hornak, "Optical distribution of clock signals in microelectronic systems," *Journal of VLSI Signal Processing: Special issue on high performance clock distribution*, vol. 16, pp. 225-246 (1997). Invited.
2. S.K. Tewksbury, "Review of Developments in Intra-System Communication Networks," *Journal of Microelectronic Systems Integration*, vol. 4(1), pp. 45-74 (1996).

Internal (unpublished) reports fully or partially based on the NASA/EPSCoR research are as follows.

1. S.K. Tewksbury, "Review of Peripheral Component Interconnection (PCI) for DSP Array Network", 1995 (available if useful)
2. S.K. Tewksbury, "Signal Flow Modeling for Parallel DSP Arrays," 1995 (available if useful)
3. S.K. Tewksbury, "General Communications Issues for Parallel DSP Arrays," 1995 (available if useful).

The research on parallel execution of computational algorithms explored the development and performance analysis of parallel algorithms for Neural Networks training procedures. The training procedures for large scale Neural Networks used in applications such as pattern recognition, vision, and speech recognition, require enormous amount of computational resources. The mass of processing elements and synaptic connections that compromise a NN, as well as the generally required large training set, make NNs inherently computationally intensive. This work proposed a new training set parallel algorithm for large-scale neural network. This algorithm was implemented for a fingerprint image comparison system. The performance of this algorithm is compared with traditional algorithms using both theoretical analysis and experimental results. An experimental test bed for NN training algorithms for the fingerprint image comparison application was implemented on a 32-node CM-5 system.

The following peer-reviewed journal publications and conference proceedings publications are fully or partially based on this NASA/EPSCoR research:

1. H. H. Ammar, S. Zeng, and Z. Miao "Parallel Processing and Fingerprint Image Comparison," in press, *International Journal of Modeling and Simulation*, Vol. 2/3, 1997.

2. H. H. Ammar, Z. Miao "A Comparison of Parallel Algorithms for the Training procedures of Neural Network based Systems", To appear in the International Journal of Supercomputer Applications and High Performance Computing, 1998.
3. H. H. Ammar, and Z. Miao "Performance of Parallel Algorithms for Fingerprint Image Comparison System," Proceedings of the Eighth International Symp. On Parallel and Distributed Processing (SPDP'96), IEEE Comp. Soc., October, 1996.
4. H. H. Ammar, and Z. Miao "Implementation of a Training Set Parallel Algorithm for an Automated Fingerprint Image Comparison System," Proceedings of the 25th International Conference on Parallel Processing (ICPP'96), IEEE Comp. Soc., August, 1996.

The following Masters Thesis is considered as the technical report summarizing this research (Z. Miao was funded through this program).

Z. Miao, "Parallel Algorithms for an Automated Fingerprint Image Comparison System", Masters Thesis, Department of Electrical and Computer Engineering, Sept. 1995.

The work on software development for parallel computing systems and investigated the feasibility of developing methods through which the mapping of sequential algorithms to parallel algorithms can be efficiently achieved for a wide class of processors. The research highlighted applications and algorithms from the general area of image processing, which provided a real-world example through which to assess mapping techniques. The work on the integration of GIS and WWW for query, retrieval and extraction of spatial data is important given the rapidly increasing demand for geographical data and the rise in popularity of Geographical Information Systems (GIS) has been fueled by the increasing availability of digital spatial data. Because of the high cost of spatial data generation, its temporal currency, scale-accuracy related issues, and a desire to avoid duplication of effort, a substantive quantity of data has traditionally been accessed over the Internet. The size of spatial databases provide particular challenges to this process. The research addressed the application of the rapidly advancing and widely dispersed World Wide Web (WWW) technology for access to and distribution of large scale information material. The research, in particular, explored the capabilities provided by the high speed data communication and the metadata search and transfer capabilities offered by the WWW.

IV. Development of Doppler Global Velocimeter (DGV) for Aeronautical and Combustion Studies

Dr. John Kuhlman, Department of Mechanical and Aerospace Engineering, West Virginia University

Funds from the NASA/EPSCoR planning grant were used to partially support MS student Senthilkumar Ramanath who then completed his degree while supported by a DEPSCoR AFOSR grant entitled "Development of Doppler Global Velocimeter (DGV) for Aeronautical and Combustion Studies". Mr. Ramanath worked with the PI and two other graduate students to develop a DGV research laboratory and a two-channel DGV velocity measurement system. His major responsibility was the development of a computer-controlled three-axis traversing system, which is used to traverse the flow systems with respect to the DGV measurement instrument.

Doppler Global Velocimetry (DGV) uses a heated, carefully temperature-controlled glass cell which is filled with molecular iodine, to measure the Doppler shift of laser light which is scattered off of small, micron-sized seed particles in an air flow. Different velocity components can be measured by viewing the flow from different viewing directions, so that the three-dimensional velocity field can be reconstructed by viewing from three different directions.

Molecular iodine vapor exhibits several absorption bands, one of which overlaps the green (514 nm) frequency of an Argon ion laser. The amount of light transmitted through the iodine cell varies as the frequency of the scattered light changes. The laser beam is spread into a two-dimensional laser light sheet which illuminates a planar region of the flow of interest. This region is viewed through the iodine cell by a video camera, which is used to record the data. Regions of different velocity result in different Doppler shift frequencies, which result in different intensities of the light which is transmitted through the cell and recorded by the video camera. To compensate for variations in light intensity across the field of view, the same region is viewed by a second video camera which does not image through the iodine cell, and with careful registration of the two images, the ratios of the gray levels of these images yields the velocity at each pixel in the video image.

The DGV technique for velocity measurement was patented and first demonstrated by H. Komine of the Northrop Corporation in 1990-91. DGV system development is currently underway at NASA Langley and NASA Ames Research Centers, the Air force Wright Laboratory, and Ohio State and Princeton Universities, as well as at WVU. Some of the NASA EPSCoR planning funds were used to travel to NASA Ames Research Center by the PI. There, the PI and Dr. Tom Beutner of Wright Laboratory met with Dr. Robert McKenzie to discuss our DGV progress, and to study his DGV system.

This DGV velocity-measuring instrument has several advantages over existing sensors. First, it is non-intrusive, and thus does not significantly alter the flow patterns being measured. Intrusive problems such as pitot probes or hot wire probes can alter the flow significantly, especially for recirculating or separated flows. Second, since velocity data are obtained in a planar imaging region, it is expected that DGV data will be acquired in less time than is required for a point measurement technique such as pitot or hot wire probes. Conventional laser Doppler velocimetry (LDV) is non-intrusive, but is a point measurement technique, which can require data acquisition times on the order of several days for a high quality data set in a complex, three-dimensional flow. DGV should enable acquisition of quality data sets in a complex, three-dimensional flow. DGV should enable acquisition of similar amounts of data in a much shorter time. This will greatly reduce the cost of such measurements, and is also expected to enable

greater insight into the physical behavior of the flow to be obtained.

The research is concentrating on carefully documenting the achievable accuracy for a typical DGV system, which is configured to measure two velocity components in a plane. In addition, the dominant error sources are being determined, and improvements to the system are being developed to further increase system accuracy. This is being done by measuring the velocity fields in several simple, known flows such as fully-developed turbulent pipe flow, jet flows, and a turbulent boundary layer flow. Also, a simple rotating disk has been used as a velocity standard. Recently, results were presented (Kuhlman, et. al., 1997) for a point system. Accuracy of the present PDV system, based on the rotating wheel velocity results, has been documented to be on the order of ± 0.6 m/sec over a velocity range of 58 m/sec (ie, approximately ± 1 % of full scale). Linearity of the present PDV system, again based on the rotating wheel data, has been found to be on the order of ± 0.3 m/sec, which is on the order of the accuracy of the individual wheel velocity settings. This linearity is on the order of 0.5% of the measured velocity range. Both of these observed accuracies are significantly better than those documented to date by other researchers. Two-component PDV velocity data have also been presented for a fully-developed turbulent pipe flow, at a Reynolds number of approximately 76,000. Turbulence intensity values agree well with earlier hot wire data, and mean axial velocity data agree reasonably well with pitot tube results. However, radial velocity results show a consistent offset error which is on the order of ten percent of the mean axial velocity. The cause of this error is currently under investigation.

The developed two-component PDV instrumentation will next be utilized to obtain further velocity data in the fully-developed turbulent pipe flow and axisymmetric jet flow facilities. These data will be compared with conventional LDV data. Similar studies are also under way, using the two-component, scanned DGV system. The ultimate goal of the present research is to optimize the system accuracies for both the point PDV and scanned DGV systems, and to carefully document the accuracies of both optimized systems, and quantify the dominant error sources for each.